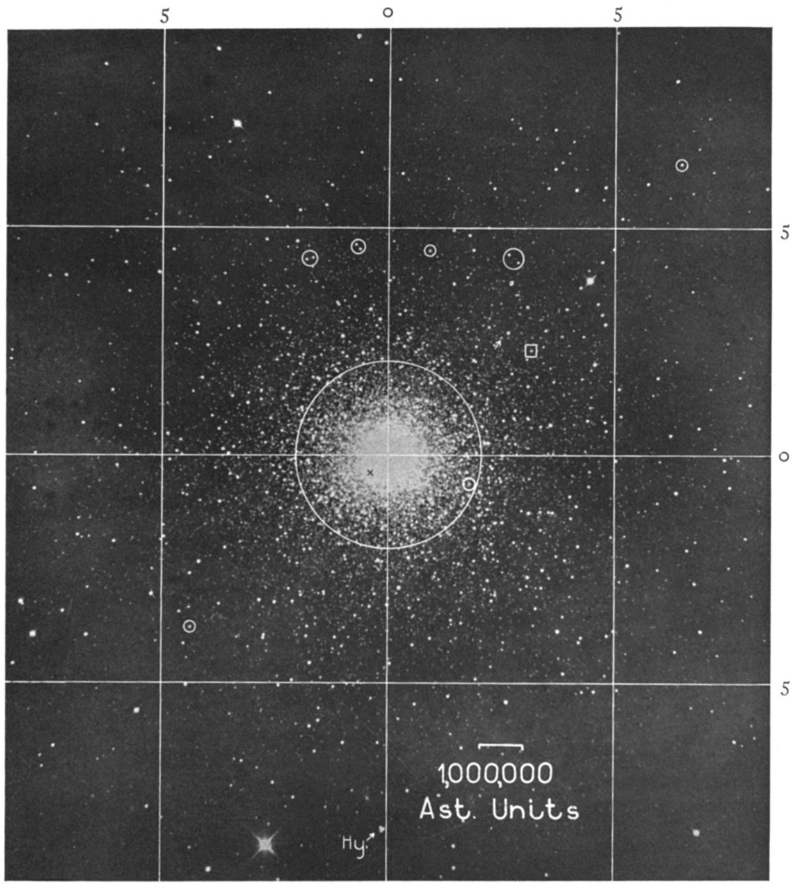


The Globular Cluster Messier 3 (N. G. C. 5272) as Seen in Projection

The side of a large square is five million times the distance of the Earth from the Sun. The radius of the concentric circle corresponds to a parallax of 0″.1 (2,060,000 astronomical units). To cross the circle light must travel for sixty-five years. Small circles contain typical variables; the small square, Variable No. 37. If the Sun were situated at the center, the *Hyades* would be at the distance of the triplet at the bottom of the picture; *Sirius* would be at the distance of the black cross near the center. A star of the luminosity of *Sirius* is indicated by the arrow point. Stars of our Sun's brightness are nearly two magnitudes too faint to appear on the photograph.

THE DIMENSIONS OF A GLOBULAR CLUSTER.

By Harlow Shapley.

Recent study of the luminosities of certain variables and of the magnitudes of stars in more than thirty clusters has led to the determination of distances for a considerable number of globular systems. The computed values, some of which are much greater than any distances heretofore determined, may be combined with the measured angular diameters of the clusters to give their dimensions in linear units. We thus find that globular clusters are immense organizations, many of them very remote from the stellar objects we usually study and possibly little connected in history and present development with the millions of stars that form our general galactic system.

The distances and dimensions of a few globular clusters had been previously estimated and their isolation in space inferred. A discussion, printed in this journal a year ago, of the stars in the well-known Hercules cluster, Messier 13, included provisional calculation of its probable dimensions. Later work, however, has shown the way to replace uncertain estimates by fairly definite measurements; and the present note contains a diagram and discussion of the actual dimensions for a typical globular cluster.

The problem of deriving the distances of clusters involves only simple and familiar operations, such as the determination of the mean luminosity of a class of stars from proper motions and radial velocities, and the study of the periods and light curves of variable stars. Hence we can place some confidence in the computed values, as much, perhaps, as we usually place in results based upon measures of magnitude and motion and upon direct methods of treatment.

Before discussing the size of a typical system, it may be of interest to mention briefly a few of the more salient features of globular clusters.

So far as now known there are about seventy stellar clusters that should be placed in the class called globular. Many listed as such in the catalogs are circular in outline or are fairly rich and compact in arrangement, but they lack the deciding characteristic of thousands or possibly hundreds of thousands of stars condensed symmetrically toward the center.

We have recently learned, however, that many of the clusters

called globular, instead of showing an exactly circular outline when projected on the sky, are symmetrically elongated, indicating a somewhat discoidal configuration rather than a spherical system. But whether globular or only approximately so, the obvious symmetry, the evidence that a steady or possibly permanent state has been reached in the distribution of the stars, suggests that globular clusters are ideal stellar systems in which the varied laws that we partially recognize for the stars near the Sun have attained a natural and final expression.

The high average radial velocity of 150 kilometers a second has been found by Slipher from ten globular clusters. The velocities of the individual stars are not known as yet, but it is quite possible that a rotation of a whole system takes place about the shortest axis of the ellipsoidal system. Stars at a distance from the center of a million astronomical units (corresponding to an angular distance of less than two minutes of arc for many clusters) would have orbital velocities greater than 25 kilometers a second, unless their periods of revolution exceed a million years; if the cluster rotates as a whole with a period of a hundred thousand years for stars at the above distance from the center in the equatorial plane, such stars on opposite sides of the center would show a difference of velocity of more than 500 kilometers a second.

Generally the brightest stars do not reveal a cluster's elliptical form. They are also peculiar in color, being much redder than our Sun, with surface temperatures two or three thousand degrees less. To emit so much light their volumes must be very large; they are, indeed, the giant stars corresponding in our galactic system to *Betelgeux* and *Antares*.

Two or three magnitudes fainter than the brightest of these red giants we find large numbers of bluish-white stars—similar in color to *Vega*, or occasionally even as blue as the characteristic bright stars in *Orion*. It is among these bluer stars that the cluster-type variable is found—a star whose light, color, radial velocity, and spectrum all undergo conspicuous cyclic variation in an interval of less than a day. The light at minimum is generally less than one-half that at maximum; but in the mean for every star of this type the light has a very definite value—almost exactly one hundred times the visual luminosity of our Sun.

Messier 3 (N. G. C. 5272), which is chosen for the present illustration of dimensions, is one of the brightest of northern globular

clusters; under favorable conditions it is visible to the naked eye near the southern edge of the constellation *Canes Venatici*, about thirteen degrees northwest of *Arcturus*. It is very rich in typical cluster-type variable stars. About 150 have been found, some at the very center and others more distant than the limits to which the cluster was formerly supposed to extend. They are remarkably similar in length of period (about thirteen hours), as well as in range of variation and in the form of light curve.

The parallax of Messier 3 is $0''.000074$ (with an estimated uncertainty of less than 20 per cent), corresponding to a distance of nearly three thousand million times the distance of the Sun from the Earth. The light we study at the present time left the cluster forty-four thousand years ago. It may be that now the variables no longer vary; perhaps the giants have changed their colors, or new ones have been formed. But four hundred centuries is only a moment on the clocks of sidereal systems; and without presenting arguments to justify the statement, we venture to maintain that the accompanying photograph represents closely conditions as they were and as they are, and that the results of our studies of colors and variations are similarly permanent.

The plate is reproduced from a photograph of several hours exposure made by Mr. Ritchey with the 60-inch reflector. The original negative shows more than twenty thousand stars outside the central burned-out area, the smallest images being fainter than the twentieth magnitude.

The unit of the rectangular coördinates is a million times the distance of the Earth from the Sun. The cluster extends beyond the limits of the photograph in all directions. The most distant variable star (undoubtedly a member of the system) is seventeen minutes of arc from the center, corresponding to a projected distance of fourteen million astronomical units. As ordinarily seen and photographed, the cluster covers an area but little larger than one of the squares, but we may be sure that its actual extent is at least twenty-five times as great; that is, the diameter is about thirty million astronomical units. To cross the cluster light must travel 470 years. The galactic system, even exclusive of the clusters, is of course much larger than this; but if we suppose the Sun situated at the center of the cluster, all stars with parallaxes greater than $0''.1$ would be included in the concentric circle. *Sirius*, one of our nearest neighbors, would be at the distance indicated

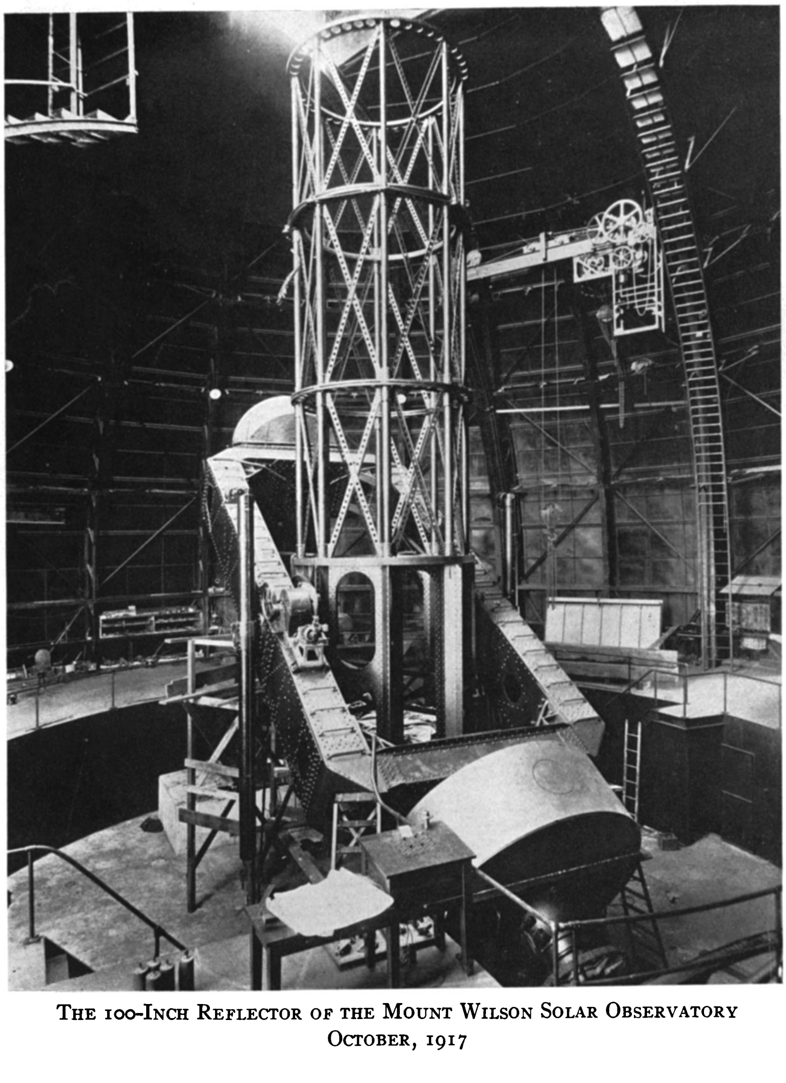
by the cross; and the projected distance of the bright triplet near the bottom of the picture is equal to the distance of the *Hyades* from the Sun.

A few of the variable stars, chosen at random, are enclosed in small circles. The close equality of their magnitudes is to be noted. In some cases they appear as doubles, but the actual separation in the nearest of the indicated pairs is more than half the distance separating the Sun from *Alpha Centauri*. In the small square is the image of an exceptional variable, No. 37, for which the period is less than eight hours. A maximum of the light curve, observed at Mount Wilson, was published in the April, 1917, issue of this journal; but that maximum actually occurred more than forty thousand years ago, and, as the star probably varies now in about the same period as then, there are fifty million other maxima of this variable star travelling thru space on their way from the cluster.

The cluster variables, in the mean, have the absolute magnitude -0.2, photographically nearly six magnitudes brighter than the Sun. A star of the brightness and color of the Sun would not appear on the photograph, being nearly two magnitudes too faint. *Sirius*, if located in this cluster, would be of the seventeenth apparent magnitude, corresponding to the faint star on the photograph indicated by an arrow point.

In conclusion we may compare the condensation of stars at the center of the cluster with that of stars around the Sun. Within the circle, which marks a distance from the center corresponding to a parallax of $0''.1$ (approximately two million astronomical units), there are at least fifteen thousand stars brighter than magnitude 20. (This estimate deducts those stars not within the concentric sphere but appearing by projection within the circular area.) In a sphere of the same radius, with the Sun as center, less than twenty stars brighter than the Sun are known. But only those which are two magnitudes brighter appear on this photograph of the cluster; there are, accordingly, in the sphere around the Sun only four or five stars to compare with the fifteen thousand in Messier 3.

Mount Wilson Solar Observatory,
November, 1917.



THE 100-INCH REFLECTOR OF THE MOUNT WILSON SOLAR OBSERVATORY
OCTOBER, 1917